REMARKS

The Office Action of April 3, 2008 has been received and its contents carefully considered.

The present Amendment places objected-to claim 18 in independent form. It also cancels objected-to claim 20, and transfers its subject matter to independent claim 14. Claim 14 thus now corresponds to objected-to claim 20 in independent form. Accordingly, it is respectfully submitted that claim 14 and its dependent claims, along with claim 18, are in condition for immediate allowance.

The present Amendment also adds new dependent claim 30 to further protect the invention. New claim 30 is supported (for example) by the sentence at page 11 of the substitute specification, lines 11-15, and the sentence at page 13, lines 9-13.

The present Amendment also corrects a paragraph on page 5 of the Substitute Specification, to state that the transparent electrically conductive film "absorbs light other than blue light" (rather than "absorbs blue light"). Since the composition of the transparent electrically conductive film is set forth in the same paragraph, it is respectfully submitted that a film of this composition would inherently absorb light other than blue light and thus this correction in the physical properties attributed to the film does not constitute new matter.

The paragraph bridging pages 5 and 6 of the Substitute Specification has likewise been corrected to state that the metal electrode "absorbs light other than blue light" (rather than "absorbs blue light"). This correction is not new matter because the composition of the metal electrode is given. Moreover, the same paragraph already states that "light other than blue light is absorbed by the metal electrode, and only blue monochrome light from

the backlight is reflected by the metal electrode." The present Amendment makes corresponding corrections in several clams.

The Office Action rejects independent claims 11 and 22 (along with a number of dependent claims) for anticipation by US patent 6,501,217 to Beierlein et al. This reference will hereafter be called simply "Beierlein" for the sake of convenient discussion. The rejection is respectfully traversed for the reasons discussed below.

The goal of Beierlein's invention was to improve prior art organic electroluminescent devices by avoiding problems associated with the anode (see column 3, lines 39-47 and lines 57-59). The reference states, "The present invention is designed to modify the existing Si device metallization into a stable OLED anode having good hole injection properties" (column 4, lines 14-16). To this end, Beierlein adds what he calls an "anode modification layer" that is "mainly selected for its high work function which provides efficient hole injection into OLEDs" (column 4, lines 35-37). The Office Action notes various features shown in Beierlein's Figure 5, including an anode modification layer 28.

Independent claims 11 and 22 both recite "a transparent electrically conductive film," and the Office Action characterizes Beierlein's anode modification layer 28 as the transparent electrically conductive film of the claims. Claims 11 and 22 go on to recite that the transparent electrically conductive film has a thickness that

> is set so as to satisfy the following equation, where L is the optical distance from the organic light-emitting layer to the metal electrode, and λ is the wavelength of light emitted by the organic light-emitting layer:
> $$L = (2n+1)\lambda/4 \qquad (n = 0,1,2,\ldots)$$

The Office Action alleges that Beierlein's arrangement "inherently satisfies the claimed equation…". Applicant respectfully disagrees.

Elementary physics textbooks frequently explore the conditions for constructive interference of light reflected from first and second parallel surfaces of a thin film based on light rays emitted from a point source. Light emitted from a point source is coherent. The light-emitting layer of an EL device, though, is an extended light source. The light emitted at one point of the light-emitting layer has a phase and polarization independent of the phase and polarization of light emitted at another point. This does not mean, of course, that interference phenomena apply only to light emitted from a point source. For example, the iridescent sheen of a thin film of oil on water arises due to interference, even if the light illuminating the thin film is not from a point source.

A copy of section 9.41 of Hecht, "Optics," second edition, Addison-Wesley Publishing Company (1987) is attached as evidence that the physics involved is not as straightforward as the Office Action would seem to imply. Attention is invited to Figure 9.13, where the wavefronts of light reflected from first and second surfaces overlap. Attention is also invited to Figure 9.17, where light is emitted from an extended source. A lens is shown in Figure 9.17 to bring light that has been emitted from a single point on the extended source and reflected at the first and second surfaces into conjunction, so that interference can be observed. The text above Figure 9.17 comments that the separation between the two reflected beams increases as the film becomes thicker, and the interference pattern disappears when only one of the two rays is able to enter the pupil of the eye.

It is common knowledge that the iridescent sheen that is seen when a thin film of oil floats on water disappears when the film of oil becomes thicker. It seems likely that the reasons for this disappearance is the extended nature of the light source and the separation

of the wavefronts of rays reflected by the first and second surfaces. At any rate, it is respectfully submitted that there is no reason to think that Beierlein's arrangement inherently satisfies the equation in independent claims 11 and 22. The aluminum contact pad 26 that is shown in Beierlein's Figure 5 will reflect light regardless of whether the equation is satisfied.

Accordingly, the rejection of independent claims 1 and 22 should be withdrawn. Claims 12, 13, and 23-31 depend from these claims and recite additional limitations to further define the invention, so they are automatically patentable along with their independent claims and need not be further discussed.

It is noted that this application has been amended to include four independent claims, and that an excess claim fee of $210 is included in a remittance that is being submitted concurrently. Should this remittance be accidentally missing or insufficient, though, any fees that may be needed can be charged to our Deposit Account number 18-0002.

For the foregoing reasons, it is respectfully submitted that this application is now in condition for allowance. Reconsideration of the application is therefore respectfully requested.

Respectfully submitted,

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upward, where the reflected rays would travel a bit farther before interfering. Because of the obvious inherent simplicity of this device, it has been used over a very wide region of the electromagnetic spectrum. The actual reflecting surfaces have ranged from crystals for x-rays, ordinary glass for light, and wire screening for microwaves to a lake or even the Earth's ionosphere for radio waves.*

All the above interferometers can be demonstrated quite readily. The necessary parts, mounted on a single optical bench, are shown diagrammatically in Fig. 9.12. The source of light should be a strong one; if a laser is not available, a discharge lamp or a carbon arc followed by a water cell, to cool things down a bit, will do nicely. The light will not be monochromatic, but the fringes, which will be colored, can still be observed. A satisfactory approximation of monochromatic light can be obtained with a filter placed in front of the arc. A low-power He–Ne laser is perhaps the easiest source to work with, and you won't need a water cell or filter.

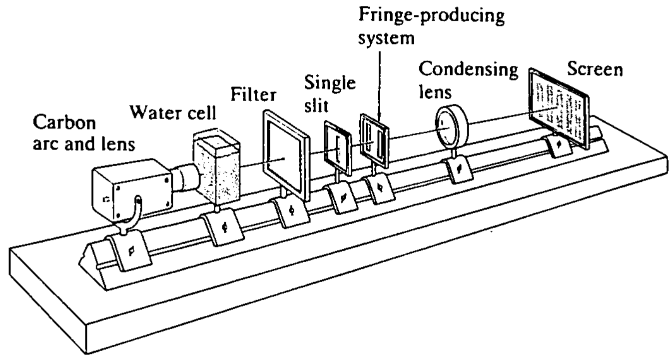


Figure 9.12 Bench setup to study wavefront-splitting arrangements with a carbon arc source.

9.4 AMPLITUDE-SPLITTING INTERFEROMETERS

Suppose that a lightwave was incident on a half-silvered mirror† or simply on a sheet of glass. Part of the wave would be transmitted and part would be reflected. Both the transmitted and reflected waves would, of course, have lower amplitudes than the original one. One might say figuratively that the amplitude had been "split." If the two separate waves could somehow be brought together again at a detector, interference would result, as long as the original coherence between the two had not been destroyed. If the path lengths differed by a distance greater than that of the wavegroup (i.e., the coherence length), the portions reunited at the detector would correspond to different wavegroups. No unique phase relationship would exist between them in that case, and the fringe pattern would be unstable to the point of being unobservable. We will get back to these ideas when we consider coherence theory in more detail. For the moment we restrict ourselves, for the most part, to those cases in which the path difference is less than the coherence length.

9.41 Dielectric Films—Double-Beam Interference

Interference effects are observable in sheet transparent materials, the thicknesses of which vary over a very broad range, from films less than the length of a lightwave (e.g., for green light λ_0 equals about $\frac{1}{150}$ the thickness of this printed page) to plates several centimeters thick. A layer of material is referred to as a *thin film* for a given wavelength of electromagnetic radiation when its thickness is of the order of that wavelength. Before the early 1940s the interference phenomena associated with thin dielectric films, although well known, had fairly limited practical applicability. The rather spectacular color displays arising from oil slicks and soap films, however pleasing aesthetically and theoretically, were mainly curiosities.

With the advent of suitable vacuum deposition techniques in the 1930s, precisely controlled coatings could be produced on a commercial scale, and that, in turn,

* For a discussion of the effects of a finite slit width and a finite frequency bandwidth, see R. N. Wolfe and F. C. Eisen, "Irradiance Distribution in a Lloyd Mirror Interference Pattern," *J. Opt. Soc. Am.* **38**, 706 (1948).

† A *half-silvered mirror* is one that is semitransparent, because the metallic coating is too thin to be opaque. You can look through it, and at the same time you can see your reflection in it. *Beam-splitters*, as devices of this kind are called, can also be made of thin stretched plastic films, known as *pellicles*, or even uncoated glass plate.

led to a rebirth of interest in dielectric films. During the Second World War, both sides were finding the enemy with a variety of coated optical devices, and by the 1960s multilayered coatings were in widespread use.

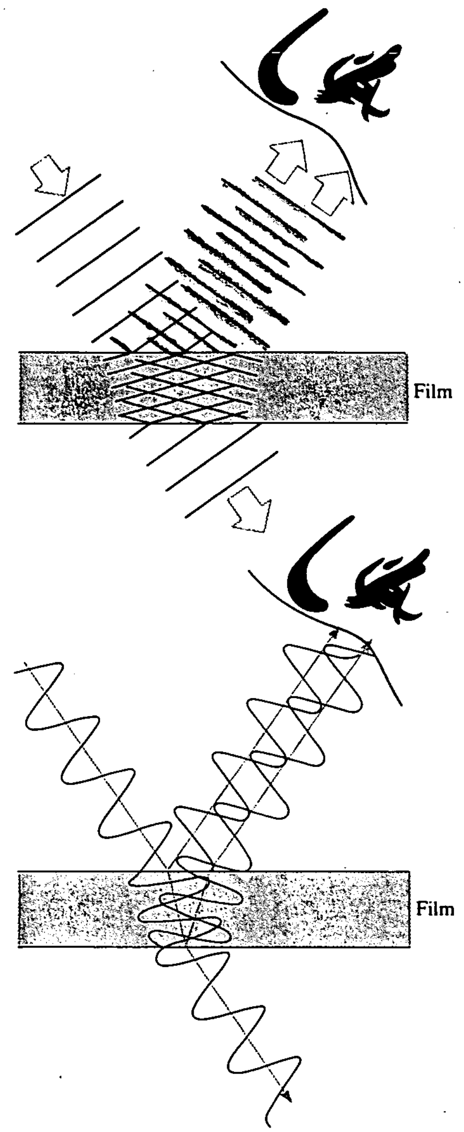


Figure 9.13 The wave and ray representations of thin-film interference. Light reflected from the top and bottom of the film interferes to create a fringe pattern.

Fringes of Equal Inclination

Initially, consider the simple case of a transparent parallel plate of dielectic material having a thickness d (Fig. 9.13). Suppose that the film is nonabsorbing and that the amplitude-reflection coefficients at the interfaces are so low that only the first two reflected beams E_{1r} and E_{2r} (both having undergone only one reflection) need be considered (Fig. 9.14). In practice, the amplitudes of the higher-order reflected beams (E_{3r}, etc.) generally decrease very rapidly, as can be shown for the air–water and air–glass interfaces (Problem 9.21). For the moment, consider S to be a monochromatic point source. The film serves as an amplitude-splitting device, so that E_{1r} and E_{2r} may be considered as arising from two coherent virtual sources lying behind the film; that is, the two images of S formed by reflection at the first and second interfaces. The reflected rays are parallel on leaving the film and can be brought together at a point P on the focal plane of a telescope objective or on the retina of the eye when focused at infinity. From Fig. 9.14, the optical path-length difference for the first two reflected beams is given by

$$\Lambda = n_f[(\overline{AB}) + (\overline{BC})] - n_1(\overline{AD}),$$

and since $(\overline{AB}) = (\overline{BC}) = d/\cos\theta_t$,

$$\Lambda = \frac{2n_f d}{\cos\theta_t} - n_1(\overline{AD}).$$

Now, to find an expression for $(\overline{AD})$, write

$$(\overline{AD}) = (\overline{AC})\sin\theta_i;$$

if we make use of Snell's law, this becomes

$$(\overline{AD}) = (\overline{AC})\frac{n_f}{n_1}\sin\theta_t,$$

where

$$(\overline{AC}) = 2d\tan\theta_t. \tag{9.32}$$

The expression for Λ now becomes

$$\Lambda = \frac{2n_f d}{\cos\theta_t}(1 - \sin^2\theta_t)$$

or finally

$$\Lambda = 2n_f d\cos\theta_t. \tag{9.33}$$

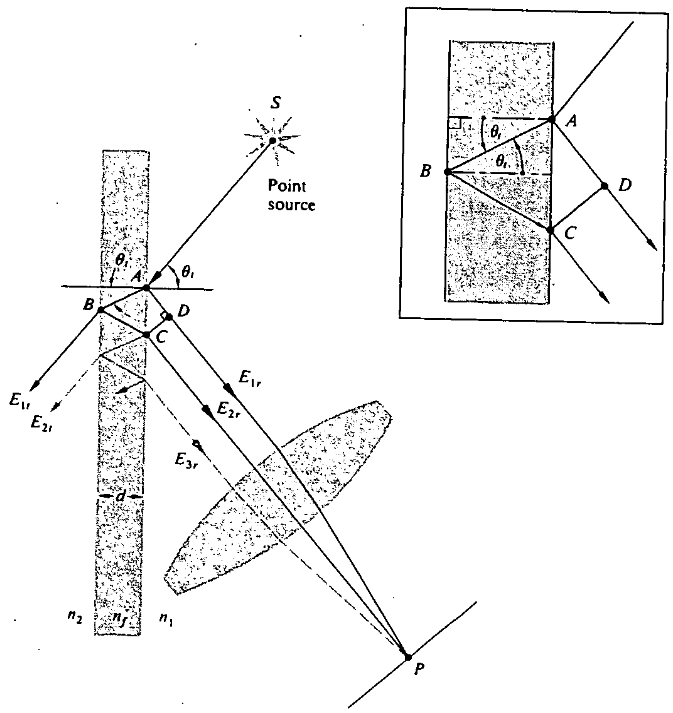


Figure 9.14 Fringes of equal inclination.

The corresponding phase difference associated with the optical path-length difference is then just the product of the free-space propagation number and Λ, that is, $k_0\Lambda$. If the film is immersed in a single medium, the index of refraction can simply be written as $n_1 = n_2 = n$. Realize, of course, that n may be less than n_f, as in the case of a soap film in air, or greater than n_f, as with an air film between two sheets of glass. In either case there will be an additional phase shift arising from the reflections themselves. Recall that for incident angles up to about 30°, regardless of the polarization of the incoming light, the two beams, one internally and one externally reflected, will experience a *relative phase shift* of π radians (Fig. 4.25 and Section 4.5). Accordingly,

$$\delta = k_0\Lambda \pm \pi$$

and more explicitly

$$\delta = \frac{4\pi n_f}{\lambda_0} d \cos\theta_t \pm \pi \tag{9.34}$$

or

$$\delta = \frac{4\pi d}{\lambda_0}(n_f^2 - n^2 \sin^2\theta_i)^{1/2} \pm \pi. \tag{9.35}$$

The sign of the phase shift is immaterial, so we will choose the negative sign to make the equations a bit simpler in form. In reflected light an interference maximum, a bright spot, appears at P when $\delta = 2m\pi$, in other words, an even multiple of π. In that case Eq. (9.34) can be rearranged to yield

$$\text{(maxima)} \qquad d\cos\theta_t = (2m+1)\frac{\lambda_f}{4}, \qquad m = 0, 1, 2, \ldots, \tag{9.36}$$

where use has been made of the fact that $\lambda_f = \lambda_0/n_f$.

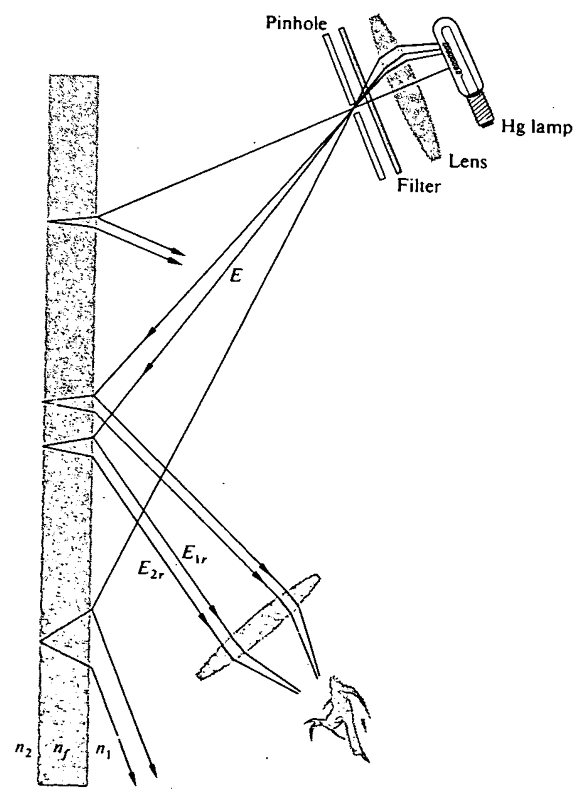


Figure 9.15 Fringes seen on a small portion of the film.

This also corresponds to minima in the transmitted light. Interference minima in reflected light (maxima in transmitted light) result when $\delta = (2m \pm 1)\pi$, that is, odd multiples of π. For such cases Eq. (9.34) yields

$$\text{(minima)} \qquad d \cos \theta_t = 2m \frac{\lambda_f}{4}. \qquad (9.37)$$

The appearance of odd and even multiples of $\lambda_f/4$ in Eqs. (9.36) and (9.37) is rather significant, as we will see presently. We could, of course, have a situation in which $n_1 > n_f > n_2$ or $n_1 < n_f < n_2$, as with a fluoride film deposited on an optical element of glass immersed in air. The π phase shift would then not be present, and the above equations would simply be modified appropriately.

If the lens used to focus the rays has a small aperture, interference fringes will appear on a small portion of the film. Only the rays leaving the point source that are reflected directly into the lens will be seen (Fig. 9.15). For an extended source, light will reach the lens from various directions, and the fringe pattern will spread out over a large area of the film (Fig. 9.16).

The angle θ_i or equivalently θ_t, determined by the position of P, will in turn control δ. The fringes appearing at points P_1 and P_2 in Fig. 9.17 are, accordingly, known as **fringes of equal inclination.** (Problem 9.26 discusses some easy ways to see these fringes.) Keep in mind that each source point on the extended source is incoherent with respect to the others.

Notice that as the film becomes thicker, the separation $(\overline{AC})$ between E_{1r} and E_{2r} also increases, since

$$(\overline{AC}) = 2d \tan \theta_t. \qquad [9.32]$$

When only one of the two rays is able to enter the pupil of the eye, the interference pattern will disappear. The larger lens of a telescope can then be used to gather in both rays, once again making the pattern visible. The separation can also be reduced by reducing θ_t and

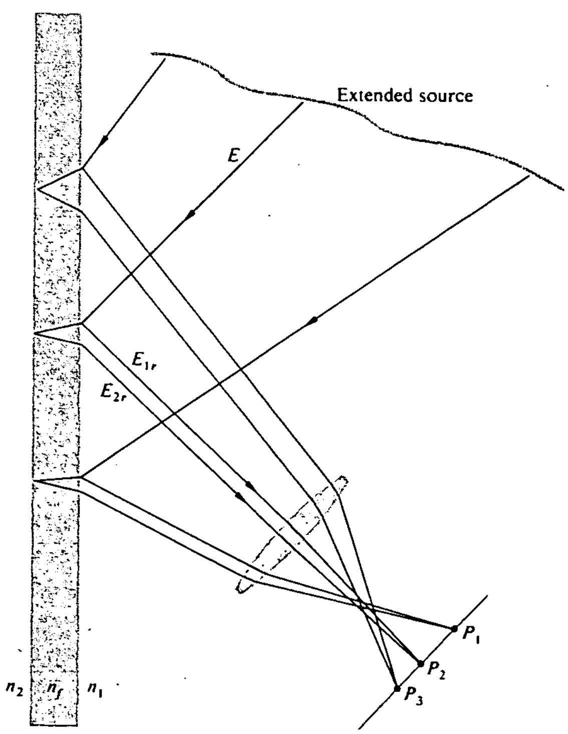


Figure 9.16 Fringes seen on a large region of the film.

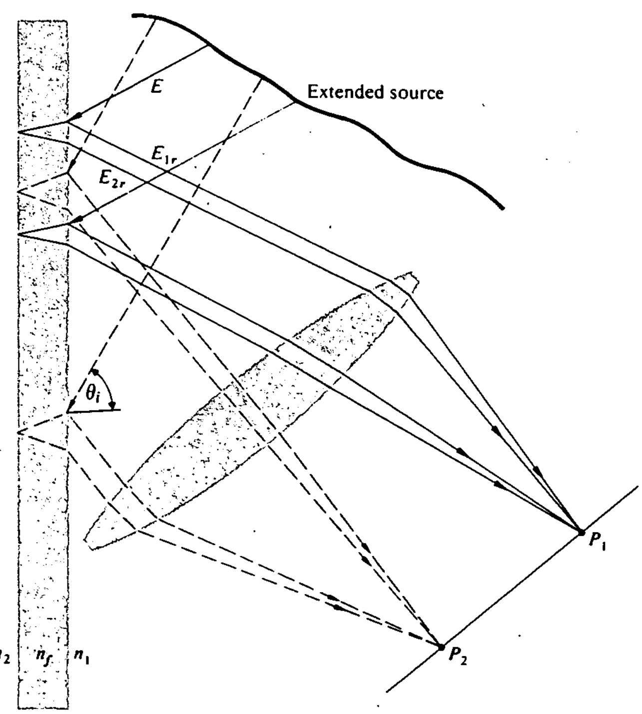


Figure 9.17 All rays inclined at the same angle arrive at the same point.

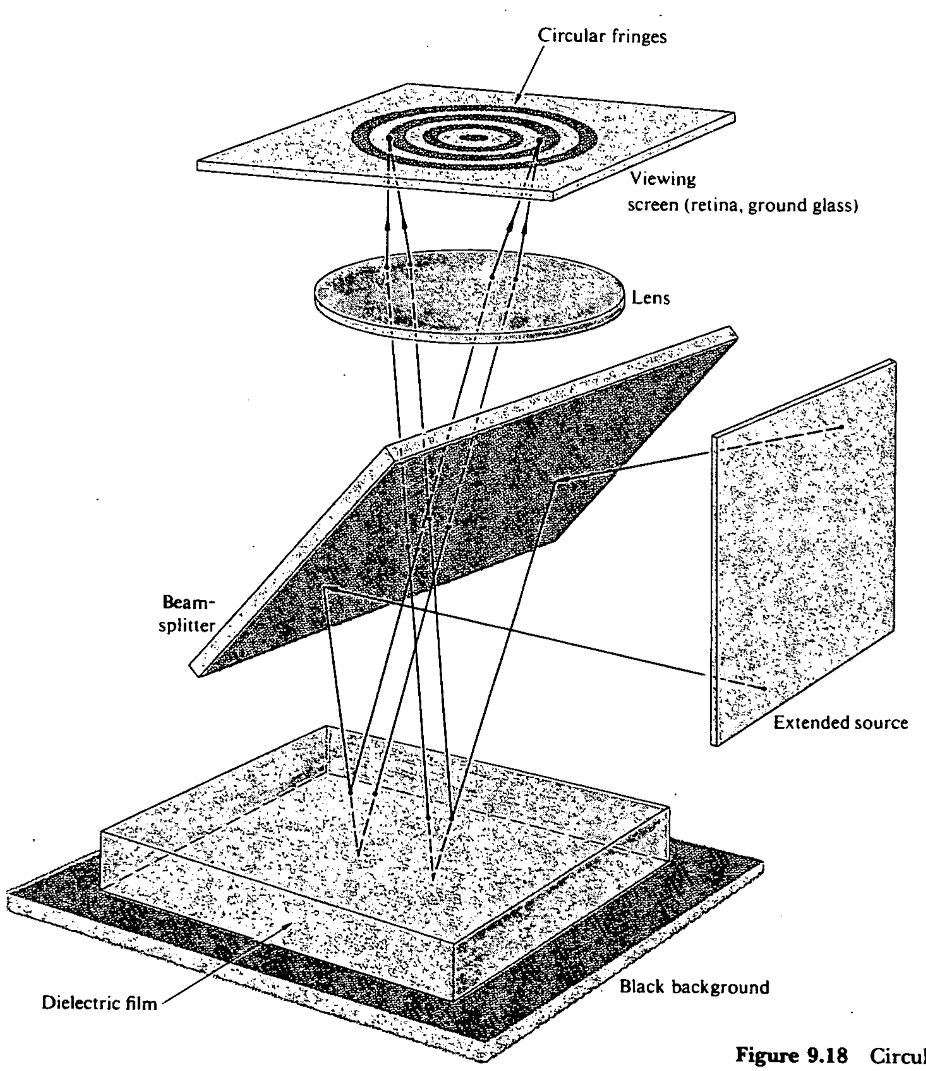


Figure 9.18 Circular Haidinger fringes centered on the lens axis.

therefore θ_i, that is, by viewing the film at nearly normal incidence. The equal-inclination fringes that are seen in this manner for thick plates are known as **Haidinger fringes**, after the Austrian physicist Wilhelm Karl Haidinger (1795–1871). With an extended source, the symmetry of the setup requires that the interference pattern consists of a series of concentric circular bands centered on the perpendicular drawn from the eye to the film (Fig. 9.18). As the observer moves, the interference pattern follows along.

Fringes of Equal Thickness

A whole class of interference fringes exists for which the optical thickness, $n_f d$, is the dominant parameter rather than θ_i. These are referred to as **fringes of equal thickness**. Under white-light illumination the iridescence of soap bubbles, oil slicks (a few wavelengths thick), and even oxidized metal surfaces is the result of variations in film thickness. Interference bands of this kind are analogous to the constant-height contour lines of a topographical map. Each fringe is the locus of all

points in the film for which the optical thickness is a constant. In general, n_f does not vary, so that the fringes actually correspond to regions of constant film thickness. As such, they can be quite useful in determining the surface features of optical elements (lenses, prisms, etc.). For example, a surface to be examined may be put into contact with an *optical flat.** The air in the space between the two generates a thin-film interference pattern. If the test surface is flat, a series of straight, equally spaced bands indicates a wedge-shaped air film, usually resulting from dust between the flats. Two pieces of plate glass separated at one end by a strip of paper will form a satisfactory wedge with which to observe these bands.

When viewed at nearly normal incidence in the manner illustrated in Fig. 9.19, the contours arising from a nonuniform film are called **Fizeau fringes**. For a thin wedge of small angle α, the optical path-length difference between two reflected rays may be approximated by Eq. (9.33), where d is the thickness at a particular point, that is,

$$d = x\alpha. \tag{9.38}$$

For small values of θ_i the condition for an interference maximum becomes

$$(m + \tfrac{1}{2})\lambda_0 = 2n_f d_m$$

or

$$(m + \tfrac{1}{2})\lambda_0 = 2\alpha x_m n_f.$$

Since $n_f = \lambda_0/\lambda_f$, x_m may be written as

$$x_m = \left(\frac{m + 1/2}{2\alpha}\right)\lambda_f. \tag{9.39}$$

Maxima occur at distances from the apex given by $\lambda_f/4\alpha$, $3\lambda_f/4\alpha$, etc., and consecutive fringes are separated by a distance Δx, given by

$$\Delta x = \lambda_f/2\alpha. \tag{9.40}$$

* A surface is said to be optically flat when it deviates by not more than about $\lambda/4$ from a perfect plane. In the past, the best flats were made of clear fused quartz. Now glass-ceramic materials (e.g., CER-VIT) having extremely small thermal coefficients of expansion (about one sixth that of quartz) are available. Individual flats of $\lambda/200$ or a bit better can be made.

Notice that the difference in film thickness between adjacent maxima is simply $\lambda_f/2$. Since the beam reflected from the lower surface traverses the film twice ($\theta_i \approx \theta_t \approx 0$), adjacent maxima differ in optical path length by λ_f. Note, too, that the film thickness at the various maxima is given by

$$d_m = (m + \tfrac{1}{2})\frac{\lambda_f}{2}, \tag{9.41}$$

which is an odd multiple of a quarter wavelength. Traversing the film twice yields a phase shift of π, which when added to the shift of π resulting from reflection, puts the two rays back in phase.

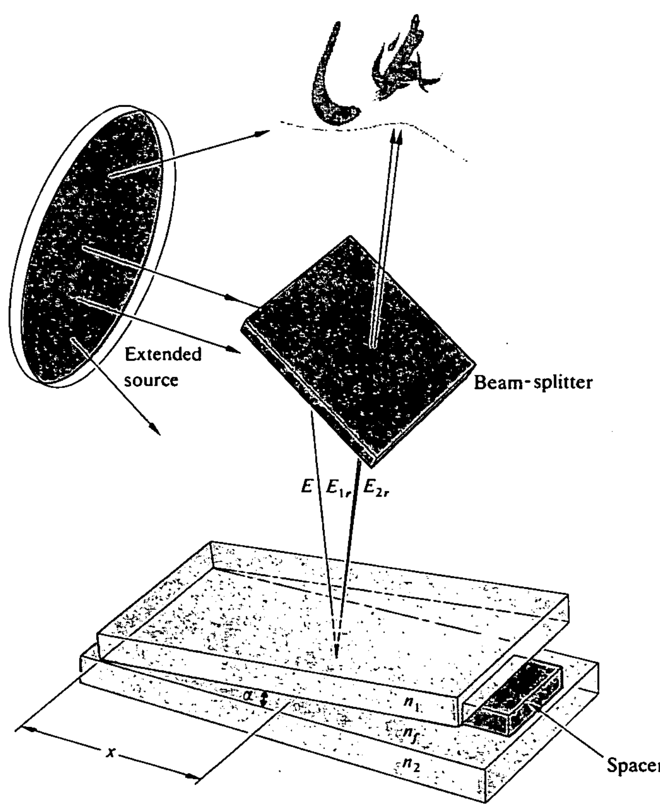


Figure 9.19 Fringes from a wedge-shaped film.

Figure 9.20 is a photograph of a soap film held vertically so that it settles into a wedge shape under the influence of gravity. When illuminated with white light, the bands are various colors. The black region at the top is a portion where the film is less than $\lambda_f/4$ thick. Twice this, plus an additional shift of $\lambda_f/2$ due to the reflection, is less than a whole wavelength. The reflected rays are therefore out of phase. As the thickness decreases still further, the total phase difference approaches π. The irradiance at the observer goes to a minimum (Eq. 9.16), and the film appears black in reflected light.*

Press two well-cleaned microscope slides together. The enclosed air film will usually not be uniform. In ordinary room light a series of irregular, colored bands (fringes of equal thickness) will be clearly visible across the surface (Fig. 9.21). The thin glass slides distort under pressure, and the fringes move and change accordingly. Indeed, if the two pieces of glass are forced together at a point, as might be done by pressing on them with a sharp pencil, a series of concentric, nearly circular, fringes is formed about that point (Fig. 9.22). Known as **Newton's rings,*** this pattern is more precisely examined with the arrangement of Fig. 9.23. Here a lens is placed on an optical flat and illuminated at normal incidence with quasimonochromatic light. The amount of uniformity in the concentric circular pattern is a measure of the degree of perfection in the shape of the lens. With R as the radius of curvature of the convex lens, the relation between the distance x and the film thickness d is given by

$$x^2 = R^2 - (R - d)^2$$

or more simply by

$$x^2 = 2Rd - d^2.$$

Since $R \gg d$, this becomes

$$x^2 = 2Rd.$$

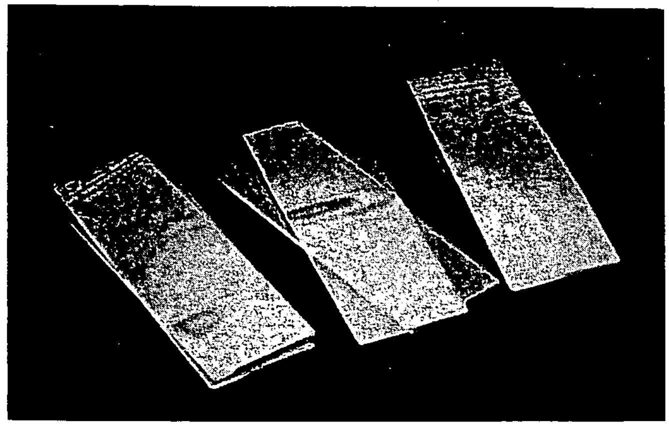


Figure 9.21 Fringes in an air film between two microscope slides. (Photo by E. H.)

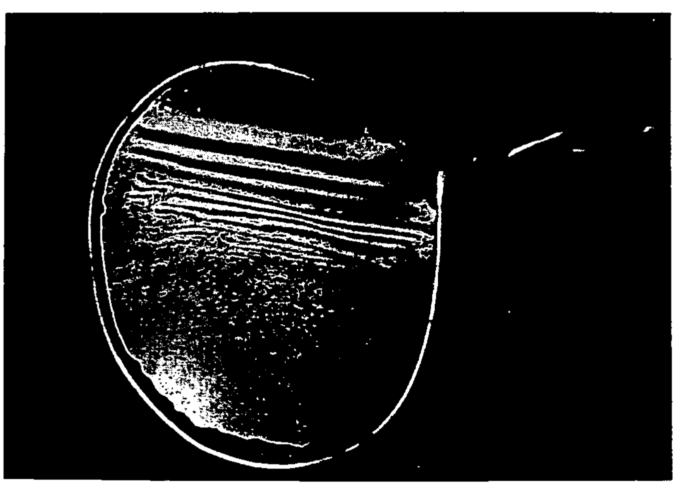


Figure 9.20 A wedge-shaped film made of liquid dishwashing soap. (Photo by E. H.)

* The relative phase shift of π between internal and external reflection is required if the reflected flux density is to go to zero smoothly, as the film gets thinner and finally disappears.

* Robert Hooke (1635–1703) and Isaac Newton independently studied a whole range of thin-film phenomena, from soap bubbles to the air film between lenses. Quoting from Newton's *Opticks:*

> I took two Object-glasses, the one a Planoconvex for a fourteen Foot Telescope, and the other a large double Convex for one of about fifty Foot; and upon this, laying the other with its plane side downwards, I pressed them slowly together to make the Colours successively emerge in the middle of the Circles.

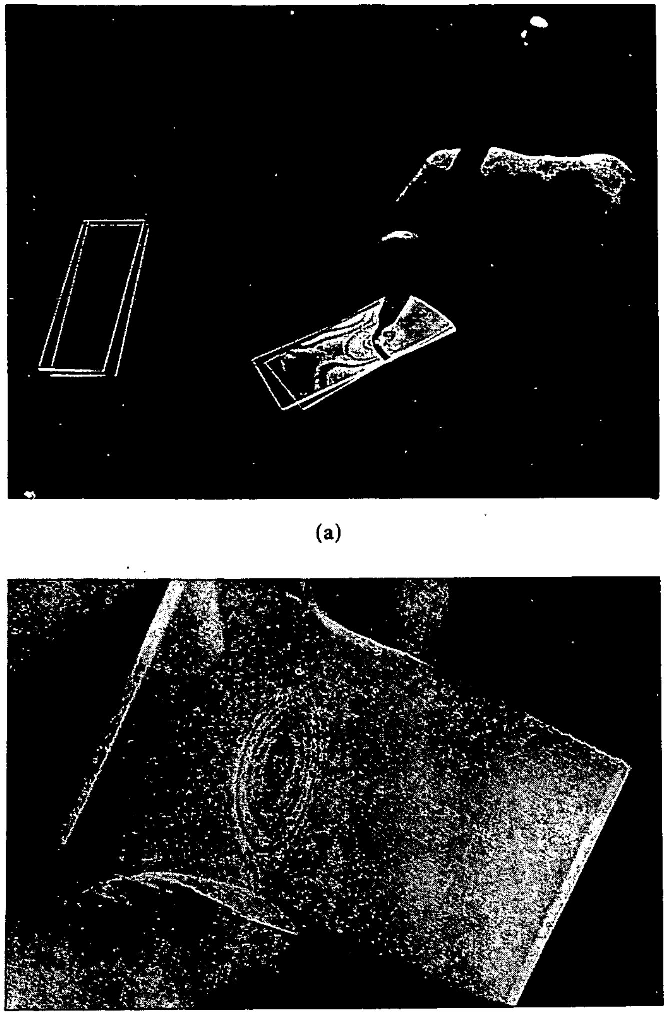


Figure 9.22 Newton's rings with two microscope slides. (Photos by E. H.)

We again approximate by assuming that we need only examine the first two reflected beams E_{1r} and E_{2r}. The mth-order interference maximum will occur in the thin film when its thickness is in accord with the relationship

$$2n_f d_m = (m + \tfrac{1}{2})\lambda_0.$$

The radius of the mth bright ring is therefore found by combining the last two expressions to yield

$$x_m = [(m + \tfrac{1}{2})\lambda_f R]^{1/2}. \qquad (9.42)$$

Similarly, the radius of the mth dark ring is

$$x_m = (m\lambda_f R)^{1/2}. \qquad (9.43)$$

If the two pieces of glass are in good contact (no dust), the central fringe at that point ($x_0 = 0$) will clearly be a minimum in irradiance, an understandable result since d goes to zero at that point. In transmitted light, the observed pattern will be the complement of the reflected one discussed above, so that the center will now appear bright.

Newton's rings, which are Fizeau fringes, can be distinguished from the circular pattern of Haidinger's fringes by the manner in which the diameters of the rings vary with the order m. The central region in the Haidinger pattern corresponds to the maximum value

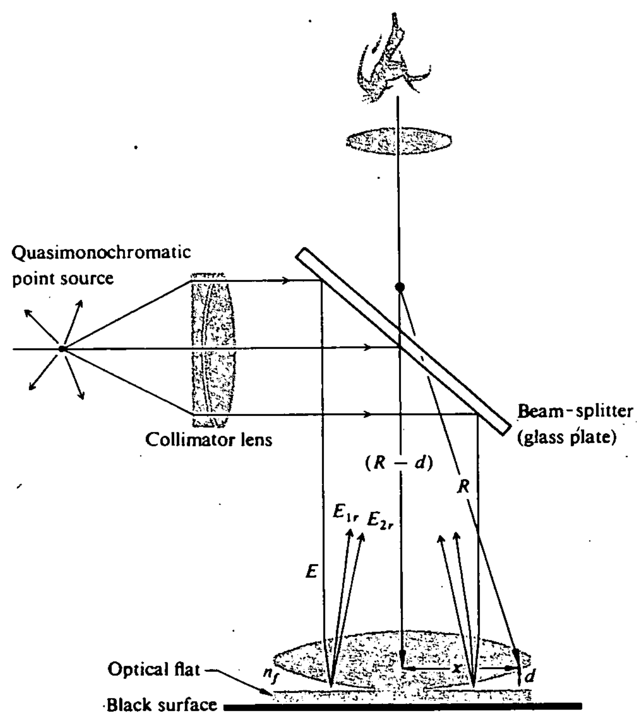


Figure 9.23 A standard setup to oberve Newton's rings.

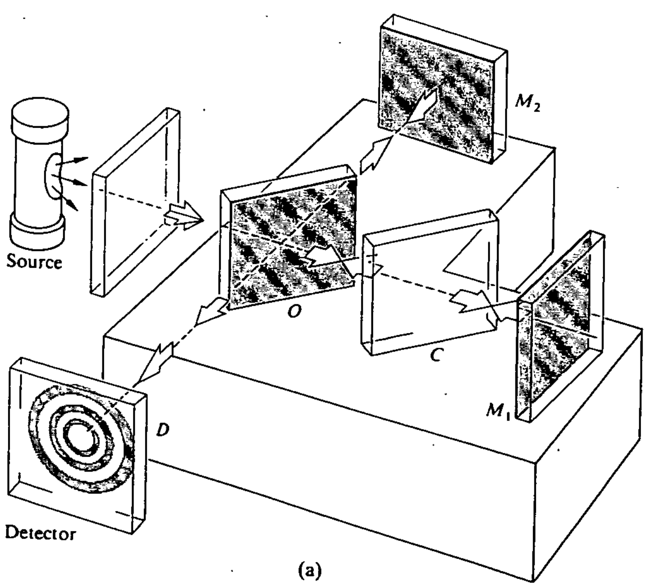
of m (Problem 9.25), whereas just the opposite applies to Newton's rings.

An optical shop, in the business of making lenses, will have a set of precision spherical test plates or gauges. A designer can specify the surface accuracy of a new lens in terms of the number and regularity of the Newton rings that will be seen with a particular test gauge. The use of test plates in the manufacture of high-quality lenses, however, is giving way to far more sophisticated techniques involving laser interferometers (Section 9.8.4).

9.4.2 Mirrored Interferometers

There are a good number of amplitude-splitting interferometers that utilize arrangements of mirrors and beam-splitters. By far the best known and historically the most important of these is the **Michelson interferometer**. Its configuration is illustrated in Fig. 9.24. An extended source (e.g., a diffusing ground-glass plate illuminated by a discharge lamp) emits a wave, part of which travels to the right. The beam-splitter at O divides the wave into two, one segment traveling to the right and one up into the background. The two waves are reflected by mirrors M_1 and M_2 and return to the beam-splitter. Part of the wave coming from M_2 passes through the beam-splitter going downward and part of the wave coming from M_1 is deflected by the beam-splitter toward the detector. Thus the two waves are united, and interference can be expected.

Notice that one beam passes through O three times whereas the other traverses it only once. Consequently, each beam will pass through equal thicknesses of glass only when a *compensator plate C* is inserted in the arm OM_1. The compensator is an exact duplicate of the



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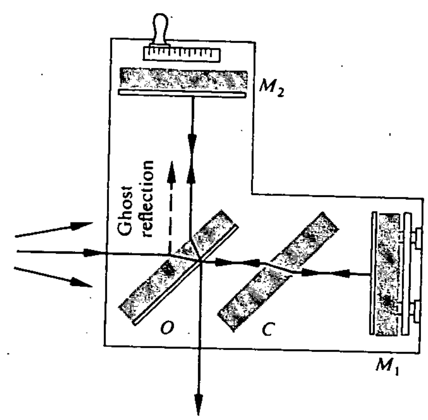

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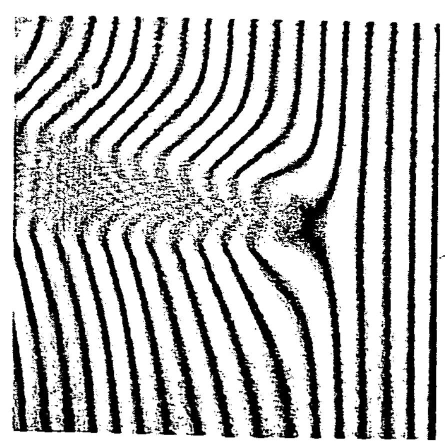

(c)

Figure 9.24 The Michelson interferometer. (c) The fringe pattern with the tip of a hot soldering iron in one arm. (Photo by E. H.)